Characterization of Mesoscale Predictability

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LONG-TERM GOALS

One of the major efforts in the atmospheric sciences has been to develop and implement high-resolution forecast models and to improve their parameterization of unresolved physical processes (boundary-layer transport, cloud microphysics…). For the last three decades, the relatively pessimistic predictions of Lorenz (1969) about the predictability of small-scale (i.e., mesoscale) atmospheric features have been largely ignored as routine weather forecasts were conducted at increasingly fine scale. Recent research suggests there are nevertheless, significant limitations to the predictability of mesoscale atmospheric circulations. Our goal is to develop an understanding of the predictability of such circulations in forecasts generated by state-of-the-art high-resolution mesoscale models.

OBJECTIVES

Specific questions addressed in our research include:

1. How commonly does the dramatic growth of initial errors occur in mesoscale meteorological settings other than the downslope windstorms investigated under our previous ONR support?
2. How sensitive are these results to different strategies for characterizing the initial spread in the ensemble generated by the Kalman filter?
3. How can ensemble forecasts be best used to identify and help predict these difficult events?

The answers to these questions are of direct benefit to Navy forecasters using COAMPS to produce aviation and other forecasts of mesoscale phenomena.

APPROACH

The P.I. and graduate student Matt Gingrich, together with Drs. James Doyle and P. Alex Reinecke of NRL, are using the COAMPS model to conduct 100-member ensemble simulations of high impact events. Under previous support we considered downslope windstorms (Reinecke and Durran, 2009), which, it had been argued, had high mesoscale predictability. More recently, we have considered the prediction of lowland snow in the Puget Sound lowlands. Both of theses weather phenomenon have

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exhibited high sensitivity to initial conditions in the sense that the spread within a large initial ensemble (either 70 or 100 members) grew vary rapidly over time scales much shorter than anticipated.

We are now extending our investigation beyond downslope winds and snow in the Pacific Northwest lowlands by conducting ensemble simulations of other weather events. Our goal is not to construct an encyclopedic survey but to try to identify another one or two other prototypical weather events where deterministic mesoscale forecasts lose reliability on relatively short time scales. For starters we will examine the ``surprise snowstorm" of January 26, 2000. We will also examine snow events that appear to have been well predicted, such as a couple east-coast storms from the winter of 2009-2010, to determine if there is a clear difference in the sensitivity to initial conditions and the rate of ensemble spreading between the poorly- and well-predicted cases. Part of the motivation for this effort is to help inform the community of the need to move beyond deterministic mesoscale forecasts, which despite all the talk about ensemble prediction, are still the backbone of military, civilian and private meteorological forecast.

WORK COMPLETED

We are writing up our recent work on the predictability of lowland snow in the Puget Sound region (done in collaboration with James Doyle and Alex Reinecke, but without ONR support to the P.I.), and this manuscript is almost complete. We received our first funding for the current project in late spring and added graduate student Mark Gingrich to the project in late June. Mark applied for permission to use some of the Navy's computing resources as soon as he arrived and he attended the COAMPS workshop at NRL Monterey this summer. The plan was for Mark to familiarize himself with our efforts by repeating the ensemble simulations of two Puget-Sound snow events using the more advanced DART system to construct the initial ensembles. A key concern in our work is that our ensembles not be over-dispersive, because if they are, the spread between ensemble members overestimates that which occurs in the real atmosphere. This could lead to an overestimate of the sensitivity to the initial conditions and an excessively negative estimate of the predictability of the event in question. Unfortunately, Mark has still not received permission to use the Navy's computers, so he has not been able to perform these tests.

Mark has, however, looked into the spread of ensembles for two idealized models created by Lorenz, the famous Lorenz (1963) model, involving three unknowns and the considerably more complex Type 2 model from Lorenz (2005), implemented with 960 unknowns. Without a procedure known as "inflation", ensembles tend to be under-dispersive, that is, they do not to exhibit enough spread over time. This is corrected by inflating the initial ensemble spread. In our earlier work on lowland snow, we used an inflation strategy know as "relaxation to the prior" (Zhang, 2004). The DART system uses spatially and temporally adaptive multiplicative covariance inflation (Anderson, 2007, 2009). Matt has performed an extensive comparison of the performance of these two inflation strategies as applied to "forecasts" generated by the idealized Lorenz models.

RESULTS

Since the project has just started and Matt has been unable to access the Navy's computers, we do not yet have a lot of results. Mark's exploration of the performance of different inflation techniques in idealized models has nevertheless yielded interesting findings. Fig. 1 compares the rate of spread of 100-member ensembles, as assessed by the variance of the first unknown variable over the ensemble,

with the square of the deviation of the ensemble mean of variable 1 from the truth over 1000 forecasts with different initial conditions (this deviation is denoted MSE, the mean square error).

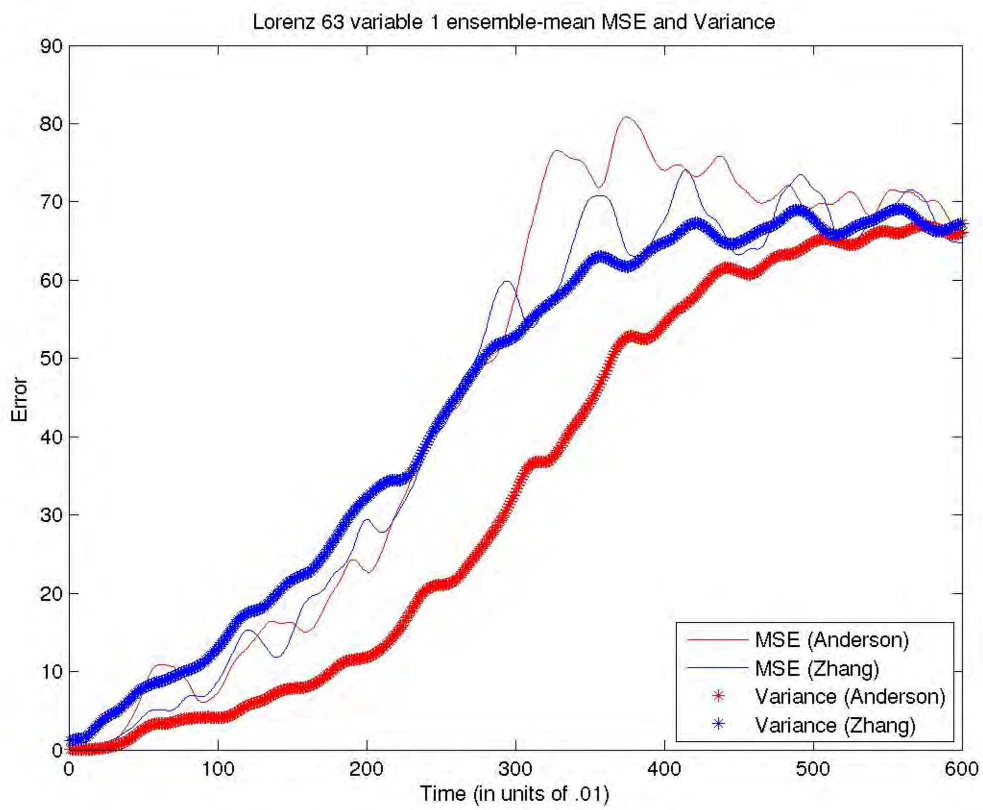

Figure 1: Comparison of the average mean square error (MSE, thin lines) of the ensemble with the average ensemble variance about the true state (stars) for variable 1 over 1000 different forecasts generated from the Lorenz (1963) model, plotted as a function of forecast lead time. The initial conditions for the ensemble forecasts were obtained using adaptive multiplicative covariance inflation (red) or relaxation-to-prior (blue).

Until the errors saturate around time 500, the ensemble variance is much smaller than the MSE when using adaptive multiplicative covariance inflation in the Lorenz 63 system (red curve lies well-above the red stars), indicating an under-dispersive ensemble. On the other hand, the MSE and the ensemble variance are comparable for the relaxation-to-prior approach (blue curve close to blue stars).

As shown in Fig. 2, relaxation-to-prior does an even better job of matching the ensemble variance to the MSE in tests with the Lorenz (2005) model. On the other hand, adaptive multiplicative covariance inflation again produces a large discrepancy between the ensemble variance and the MSE until the error gets close to saturation about day 90. Yet in contrast to the Lorenz 1963 problem, the ensembles produced by multiplicative covariance inflation are now over dispersive (red-stars above the red curve in Fig. 2).

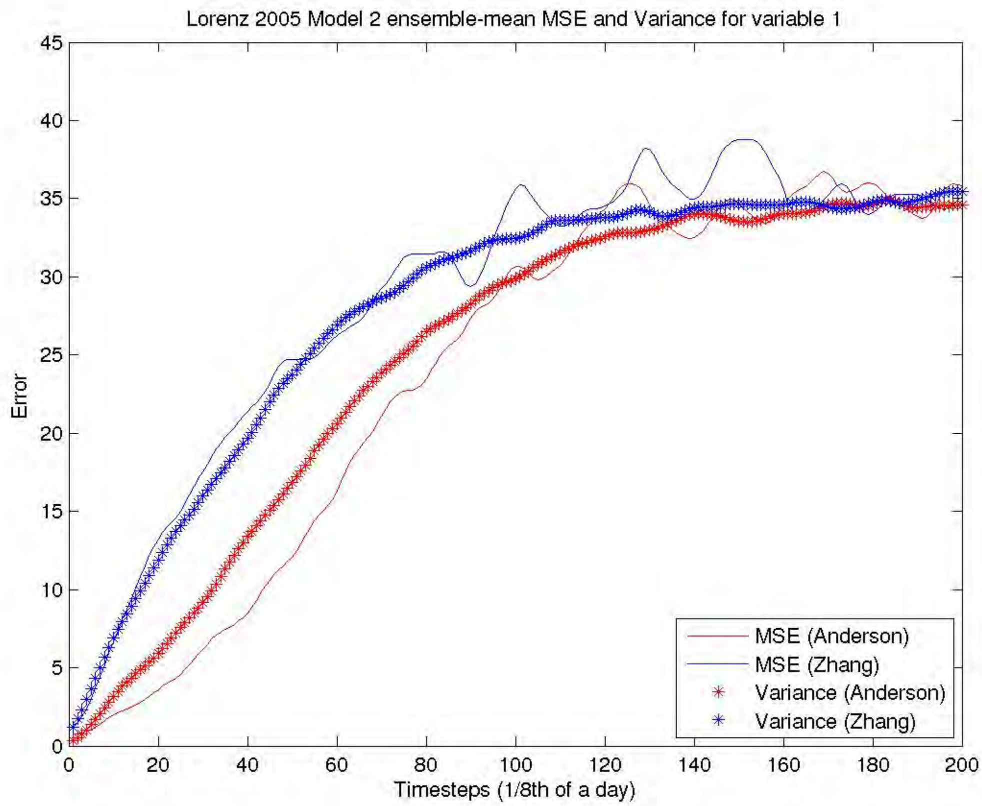

Fig. 2: As in Fig. 1, except for a 960-variable implementation of Lorenz (2005), Model 2.

We are continuing to assess the implications of theses results for the optimal inflation strategy to use in our mesoscale predictability experiments.

IMPACT/APPLICATIONS

Forecasting mesoscale meteorological phenomena is of importance to many naval operations, including those in coastal zones, those involving aviation in complex terrain, and those requiring information about the structure of the planetary boundary layer. Understanding the degree of confidence that can be realistically expected from fine-scale deterministic weather forecasts at various lead times will help meteorologists and other users assess the importance of alternative approaches, such as ensemble forecast systems.

TRANSITIONS

Beginning graduate student Matt Gingrich joined the project this summer

RELATED PROJECTS

None

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PUBLICATIONS

Reinecke, P.A., D. R. Durran, and J. Doyle, 2011: Predictability of Pacific Northwest snowstorms. In preparation.